This Page Blank (uspto)

(71) Applicant *(for all designated States except US)*: RESOUND
CORPORATION [US/US]; 220 Saginaw Drive, Seaport
Centre, Redwood City, CA 94063 (US).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: KERNS, Robert, Q.
[US/US]; Apartment #10, 1735 Marco Polo Way,
Burlingame, CA 94010 (US).

(74) Agent: KREBS, Robert, E.; Burns, Doane, Swecker & Mathis,
L.L.P., P.O. Box 1404, Alexandria, VA 22313-1404 (US).

(54) Title: BANDWIDTH MANAGEMENT IN A HETEROGENOUS WIRELESS PERSONAL COMMUNICATIONS SYSTEM

(57) Abstract

Bandwidth management techniques are provided for use in heterogenous wireless personal communications systems, designed to minimize or eliminate interference between different personal communications units. Such units may be of various types including, for example, hearing health care units, telecommunications headsets and multimedia headsets. A bandwidth resource is shared among multiple autonomous communications systems in which a Remote Processing Unit and headset pair are coupled by a slotted wireless communications link. One of a pair of devices transmits real-time information to the other device of the pair. When difficulty is experienced receiving the real-time information because of interference from a different device pair, any of several different measures may be applied including physical adjustments such as (in an RF system) diversity and/or power control. If these adjustments are insufficient, a jump procedure may be performed in which the pair of devices jump to a different portion of the bandwidth resource determined to be free. A first negotiation procedure may be performed in which the Remote Processing Unit aligns its timebase to that of a selected other Remote Processing Unit; or a second negotiation procedure may be performed in which the Remote Processing Unit and the headset agree to cease exchanging audio information within one or more particular timeslots.

BANDWIDTH MANAGEMENT IN A HETEROGENOUS WIRELESS PERSONAL COMMUNICATIONS SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

5   The present invention relates to wireless personal communications systems, particularly RF nanocell personal communications systems.

State of the Art

Wireless personal communications systems are known as exemplified by published International Application WO 96-41498 entitled Hearing Aid With Wireless

10   Remote Processor, incorporated herein by reference. As described therein, a hearing aid system consists of an earpiece that can be hidden in the ear canal, and which communicates wirelessly with a remote processor unit (RPU). The RPU may be a belt pack, wallet or purse-based unit. Sounds from the environment are picked up by a microphone in the earpiece and sent with other information over a primary two-way

15   wireless link to the RPU, where the audio signals are enhanced according to the user's needs. Signal processing is performed in the RPU rather than the earpiece to take advantage of relaxed size and power constraints. The enhanced audio signals may be combined with other information and transmitted from the RPU over the primary wireless link to the earpiece, where they are converted by a speaker to sounds that can

20   only be heard by the user.

In an exemplary embodiment, communications between the RPU and the earpiece follow an interrogate/reply cycle. The reply portion of the primary wireless link (from the earpiece to the RPU) may use a reflective backscatter technique in which the RPU radiates a carrier signal and the earpiece uses a switch to change between a

25   high backscatter antenna state and a low backscatter antenna state. An additional, optional secondary two-way wireless link can be used for communication between the RPU and a cellular telephone system or other source of information. Furthermore, an

RPU keyboard, or voice recognition capabilities in the RPU, can be used to control hearing aid parameters and telephone dialing functions. Two earpieces and an RPU can be used in a binaural wireless system that provides hearing protection and noise cancellation simultaneous with hearing aid functions.

5   Although the system of WO 96-41498 arises out of the field of hearing health care, as may be appreciated from the foregoing description, the system is more broadly applicable to personal communications in general. Recently, attention has been drawn to the application of wireless personal communications systems to telecommunications and computing. At "ACM97: The Next 50 Years of Computing", for example, the

10 prediction was made that in the future, personal computers will be wrist-sized, accompanied by a pair of reading glasses that present high-resolution images at a comfortable distance. A small, fitted earpiece and a "finger mouse" will be linked to other devices with low-power radio signals. Such a future is not far off.

       One of the challenges presented in personal communications systems is to allow

15 multiple such systems to function in close proximity to one another with no performance degradation (or graceful degradation) due to interference. An unofficial benchmark developed by the present assignee to test for robustness of communications in the presence of interference has been the "ten-person hug." That is, ten persons each with a personal communications system of the type described should be able to form

20 a group hug without experiencing significant performance degradation of their respective personal communications systems.

       Techniques for avoiding interference in personal communications systems of the foregoing type are described in WO 96-41498, Figure 6 and accompanying description. Time division multiplexing techniques are used to share bandwidth among different

25 systems.   Multiple timeslots (e.g., ten or more) are defined, each timeslot accommodating a single interrogate/reply cycle. Each RPU contains a circuit know as a "sniffer", operational only when the RPU interrogator is not transmitting, that detects the presence of other interrogators. Before an RPU initiates an interrogate/reply cycle, it performs a clear channel assessment procedure in which it listens for other

30 communications. This allows the RPU to determine whether or not other interrogators

are nearby, as well as the time intervals during which nearby interrogators are transmitting. A timeslot selection procedure then follows. If no slots are occupied, the RPU is free to initiate an interrogate/reply cycle in any timeslot. If one or more timeslots are occupied but not all, the RPU randomly chooses a timeslot following an

5 occupied timeslot in which to initiate an interrogate/reply cycle. If all timeslots are occupied, the RPU randomly selects a timeslot, repeated times if necessary, and attempts interrogation until interrogation is successful.

The timeslot selection procedure may or may not force other interrogators to change their timeslot selections due to interference, depending on relative geometry

10 considerations. As users move around, their personal communications systems automatically adapt by continually finding new acceptable steady-state solutions using the foregoing time division multiplexing technique.

The foregoing mechanism described in WO 9641498 is relied upon exclusively for avoiding interference of multiple communications devices. This type of "jumping",

15 however, is best described as a "free-for-all," each device jumping to satisfy its own communications needs without regard to other communications devices.

Although the foregoing interference avoidance technique is somewhat successful, it results in rapid degradation as the number of communications devices increases. It is not adequate to assure, to the greatest degree possible, interference-free

20 operation of multiple personal communications systems in close proximity, especially where those personal communications systems may be of diverse types. Various types of personal communications systems are expected to include, among others, hearing health care units, telecommunications headsets, and multimedia headsets.

What is needed, then, is bandwidth management techniques for use in

25 heterogenous wireless personal communications systems that assure, to the greatest degree possible, interference-free operation of multiple, possibly diverse, personal communications systems in close proximity. The present invention addresses this need.

SUMMARY OF THE INVENTION

The present invention, generally speaking, provides bandwidth management techniques for use in heterogenous wireless personal communications systems, designed minimize or eliminate interference between different personal communications units.

5 Such units may be of various types including, for example, hearing health care units, telecommunications headsets and multimedia headsets. In one embodiment of the invention, a bandwidth resource is shared among multiple autonomous communications systems in which a Remote Processing Unit and headset pair are coupled by a slotted wireless communications link. One of a pair of devices transmits real-time information

10 to the other device of the pair. When difficulty is experienced receiving the real-time information because of interference from a different device pair, any of several different measures may be applied including physical adjustments such as (in an RF system) diversity and/or power control. If these adjustments are insufficient, a jump procedure may be performed in which the pair of devices jump to a different portion

15 of the bandwidth resource determined to be free. A first negotiation procedure may be performed in which the Remote Processing Unit aligns its timebase to that of a selected other Remote Processing Unit; or a second negotiation procedure may be performed in which the Remote Processing Unit and the headset agree to cease exchanging audio information within one or more particular portions of the shared bandwidth resource.

20   BRIEF DESCRIPTION OF THE DRAWING

The present invention may be further understood from the following description in conjunction with the appended drawing. In the drawing:

Figure 1 is block diagram of a personal communications system in which the present invention may be used;

25   Figure 2 is a block diagram showing in greater detail the RPU of Figure 1;

Figure 3A through Figure 3K illustrate various registers of the RPU of Figure 2;

Figure 4 is a block diagram showing in greater detail the headset of Figure 1;

Figure 5 through Figure 11 illustrate various communications scenarios to

30 which the bandwidth management techniques of the present invention may be applied;

Figure 12 is a graph used to illustrate the effect of a synchronization policy applied by the present bandwidth management techniques; and

Figure 13A and 13B illustrate the basic structure of packet formats that may be used by the RPU and headset.

5   DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described in the context of an RF wireless personal communications system. The invention is equally applicable to wireless communications systems of various description, including infrared, ultrasonic, etc.

Referring now to Figure 1, a personal communications system in which the 10 present invention may be used includes a Remote Processor Unit (RPU) 110 and a headset 120 that achieve bidirectional communication through an RF or other wireless link. The term "headset" is used herein to denote a single earpiece, two earpieces, headphones, etc. If one or more earpieces are used, the earpiece or earpieces may be of any of various types, including BTE (Behind The Ear), ITE (In The Ear), etc. In 15 a preferred embodiment, the bidirectional communications link is substantially similar to that disclosed in the full-featured embodiment of WO 96-41498.

The RPU 110 includes a main processing unit 101 and one or more antennas (102a-102e) for transmitting and receiving information to and from the headset. In the case of the illustrated RF system, the RPU preferably includes multiple antennas for 20 diversity transmission, diversity reception, or both. The RPU may also include an external interface 103 for receiving information from an external source.

The headset 120 includes a main processing unit 105, an antenna 107, a microphone 104 and a speaker or display 106.

Referring to Figure 2, the RPU 110 is microcontroller based. Input and output 25 of information to and from the microcontroller 201 is accomplished through a digital interface unit 202. The digital interface unit 202 is coupled in turn to an I/O section 210 and an RF section 220.

The microcontroller 201 supports at least two key operational functions: nanocell master protocol management and RPU management. Nanocell master protocol

management includes such tasks as constantly monitoring signal conditions to select the correct antenna for the next set of packets and selecting the correct timeslot(s) for the RPU and headset to operate in RPU management includes such tasks as monitoring RPU battery conditions, monitoring RPU state, performing RPU setup functions, and
5   accepting headset setup functions to be sent to the headset.

The digital interface unit 202 connects the microcontroller 201 to all other subsystems within the RPU. It performs real-time data protocol management including such tasks as: a) Accepting a steady state digital input stream and providing it as packets to the RF transmitter as required; b) Accepting received RF packets and
10   performing any ECC functions to provide a steady digital output stream; c) Providing a means to use the RF link for control functions; and d) Providing any external timing required to support the D/A and A/D operations.

The I/O section 210 provides for both analog and digital input and output. Digital I/O is performed by an external digital interface 209. An analog input signal
15   213 is digitized using an A/D converter 212 and input to the digital interface unit. An analog output signal 211 is produced by a D/A converter 210 in response to data from the digital interface unit 202.

The RF section 220 includes both a transmitter 203 and a receiver 208 and optionally provides for transmit and receive diversity. The transmitter accepts a digital
20   modulation data stream and control signals and provides an RF output to a specific antenna or antennae to provide the strongest signal to the headset. The receiver accepts control signals used to select the correct antenna and provides a digital data stream that is the output from the RF receiver. The transmitter is therefore coupled to a transmit antenna selector 204, which selects from among multiple transmit antennae (205a-205e)
25   for transmitting information to the headset. The receiver 208 is coupled to a receive antenna selector 207, which selects from among multiple receive antennae (206a-206e) for receiving information from the headset.

System timing is controlled by a counter or master timer (not shown) which is used to control critical timing issues. This counter operates at four times the data bit

rate. Each data bit time is divided into four clock times with the potential of choosing one of eight clock phases (four non-inverted and four inverted phases).

More particularly, in an RF communications system in the ISM band, because of the very small wavelength of the system, very slight changes in position can result
5 in a 180° phase shift of the received signal. A sync pulse beginning each transmission is used to determine the appropriate phase. In one embodiment, a sync pulse is indicated by a first transition followed three data bit times later by an opposite transition. The direction of the transition determines the appropriate clock phase to be used for the remainder of the transmission.

10   Accessible to the microprocessor 201 are various registers used in performing bandwidth management in a manner described hereafter. In an exemplary embodiment the registers are located within the digital interface 202 and are accessed by the microprocessor through interface registers shown in Figure 3A using a well-known mechanism. Referring to Figure 3B, Primary Status Registers include a Phase Position
15 Register, a Sync Count/Status Register, a Header Count/Status Register, a Header ECC Count/Status Register, a Data Count/Status Register and a Data ECC Count/Status Register. These primary registers are used to "capture" information for subsequent storage in the individual Timeslot registers of Figure 3D-3I. More particularly, at the beginning of each timeslot, the contents of registers used to store information for that
20 timeslot are loaded into the Primary Status Registers. During the timeslot, the contents may be altered according to events occurring during the timeslot. At the end of the timeslot, the contents of the Primary Status Registers may or may not be saved.

The following paragraphs describe in detail the function of the various registers.

PHASE POSITION:
25   Address: 0,1

This register is a temporary holding register which records the phase position as compared to the unit's current clock phase.

SYNC COUNT/STATUS:

Address 2,3

The first eight bit register contains the count of the number of good sync pulses received. The count is incremented for each good one and is decremented for each bad

5 one. This counter is used to indicate how stable sync pulse reception has been. If the counter is greater than zero, then although the unit may not currently be receiving sync pulses, it has received enough sync pulses to assume that the unit may still be in sync. If the count = 0 a lost sync condition is declared. The unit must then focus on finding a sync pulse. The second eight bit register is a shift register which indicates in which

10 of the last eight frames a good sync pulse has been received. A 1 indicates a good sync pulse, 0 indicates a bad sync pulse. This register shows the state of the sync flag for the last eight frames allowing the system to view in real-time the quality of the signal and to perform corrective actions to improve the signal quality if required.

HEADER COUNT/STATUS:

15   Address: 4,5

The first eight bit register contains the count of the number of good header frames received. The count for each good one is incremented, decremented for a bad one. This counter is used to indicate how stable header data reception has been. If the counter is greater than zero then several good header data sections have been received

20 in the past. If the count = 0 a lost header condition is declared. The second eight bit register is a shift register which indicates in which of the last eight frames a good header byte has been received. A 1 indicates a good header, 0 indicates bad header data.

HEADER ECC COUNT/STATUS:

25   Address: 6,7

The first eight bit register contains the count of the number of totally error free headers received. The count is incremented for each good one, decremented for a bad one. This counter is used to indicate how much error correction is occurring on an ongoing basis. If the counter is greater than zero then the EC subsystem is being

30 required to do data recovery work. If the count = 0 then the ECC subsystem is

reporting no bit errors in the received data (a very good sign). The second eight bit register is a shift register which indicates in which of the last eight frames a perfect header has been received. A 0 indicates ECC was required, 1 indicates the header was error free.

5   DATA COUNT/STATUS:

Address: 8,9

The first eight bit register contains the count of the number of good data frames received. The count is incremented for each good one, decremented for a bad one. This counter is used to indicate how stable the data reception has been. If the counter

10 is greater than zero then several good data sections have been received in the past. If the count = 0 a lost data condition is declared. The second eight bit register is a shift register which indicates in which of last eight frames good header byte data has been received. A 1 indicates good data, 0 indicates bad data.

DATA ECC COUNT/STATUS:

15   Address: 10,11

The first eight bit register contains the count of the number of totally error free data packets received. The count is incremented for each good one, decremented for a bad one. This counter is used to indicate how much error correction is occurring on an ongoing basis. If the counter is greater than zero then the EC subsystem is being

20 required to do data recovery work. If the count = 0 then the ECC subsystem is reporting no bit errors in the received data (a very good sign). The second eight bit register is a shift register which indicates in which of the last eight frames sync pulse a perfect data packet has been received. A 0 indicates ECC was required, 1 indicates the data was error free before any ECC processing.

25 INTERNAL COMMAND/STATUS A:

Address: 12, 13

These registers are the command and status register group A.

INTERNAL COMMAND/STATUS B:

Address 14, 15

30   These registers are the command and status register group B.

Referring to Figure 3C, data transfer registers are provided for transmitting and receiving data pockets. In an exemplary embodiment, data packets are allowed to have a maximum length of 32 words.

Referring to Figure 3D, Phase Position Registers are provided for each timeslot.

5 Although in a preferred embodiment ten timeslots are used, Phase Position Registers are provided for 16 times slots, Timeslot 0 through Timeslot 15, allowing for future expansion. The Phase Position Registers are used to maintain sync between multiple units which each maintain their own local control. Clock drift between the multiple units is inevitable. These registers allow each unit to track the relative time alignment

10 of the other units operating within the same space.

Referring to Figure 3E, Sync Status Registers are provided for each timeslot. In the illustrated embodiment, the high byte of each register stores a Sync Count, and the low byte of each register stores Status information for the last eight frames. As previously described, the Sync Count for a particular timeslot is incremented for each

15 frame that "good sync" was received for that timeslot. A sync pulse is a distinctive pattern disallowed in accordance with the data encoding that is employed (for example Manchester encoding). During sync acquisition, devices look for sync pulses continuously. After sync has been acquired, a device looks for a sync pulse within a specified sync window. The Sync Count is decremented for each frame that bad sync

20 (the lack of good sync) occurs. The Status Registers store synchronization status for each timeslot for the last eight frames. For example, a value of 11111110 would indicate that bad sync occurred in the most recent frame but that good sync was received in the preceding seven frames. If in the next frame good sync was again received, the value would be updated to 11111101.

25 The Header Status Registers, Header ECC Status Registers, Data Status Registers and ECC Status Registers of Figure 3F through Figure 3I, respectively, are used in a similar manner as the Sync Status Registers of Figure 3B. For each frame that a good header or data packet is received for a particular timeslot, the corresponding count is incremented. When the header or data packet is bad, the count

30 is decremented. The status portion of the registers gives a history of the most recent

- 10 -

eight frames, whether a good header or data packet was received or the header or data packet was bad.

A data packet may be bad but correctable using ECC. The use of ECC should be minimized, however, to conserve power. Referring to Figure 3I, each time ECC checking reveals a perfect data packet, the ECC Count is incremented. Each time that error correction must be attempted, the ECC Count is decremented. The status portion of the registers gives a history of the most recent eight frames, whether error correction had to be attempted or not.

Referring to Figure 3J, registers are also provided for storing by timeslot the serial numbers of other RPUs within range of the present RPU. In the illustrated embodiment, the serial numbers are four bytes long. For each timeslot, a further register 301J is provided in which a "vision count" is stored of the number of RPUs within range of each of the RPUs that are within range of the present RPU. During Serial Number Exchange, described in greater detail below, each RPU broadcasts how many RPUs are within range of it (i.e., how many entries it has within the Serial Number registers of Figure 3J). Each RPU stores this information in the respective count registers of Figure 3J for use during Slot Negotiation, described hereinafter. Serial Number Exchange is executed periodically by each RPU.

The information stored in the registers of Figures 3A-3J in essence represents a snapshot of the current communications environment as seen by a particular RPU. The snapshot is updated at the frame rate, 2000 times per second in a preferred embodiment. This real-time information allows for intelligent cooperative interaction of the different RPUs to achieve distributed, collective bandwidth management in an efficient manner.

Referring to Figure 3K, in addition to the foregoing registers there are provided Control and Status Registers. The registers are used to store status and control information for up to two earpieces (Earpiece A and Earpiece B). Information is stored concerning sample size and sample rate in the uplink and downlink directions. The parameters may be varied through Bandwidth Negotiation described in greater detail

below. Finally the serial numbers of the RPU and the serial number of its matching earpieces (each eight-byte quantities) are stored.

Referring to Figure 4, the headset will be described. The headset is microcontroller-based. Input and output of information to and from the microcontroller
5 401 is accomplished through a digital interface unit 402. The digital interface unit 402 is coupled in turn to an I/O section 410 and an RF section 420.

The I/O section 410 provides for both analog and digital input and output. Digital I/O is performed by an external digital interface 405. An analog input signal (mic input) is produced by a microphone 409 that picks up ambient sounds. The mic
10 input is digitized using an A/D converter 408 and input to the digital interface unit 402. An analog output signal (audio out) is produced by a D/A converter 406 in response to data from the digital interface unit 402. The audio out signal is applied to a speaker 407. Of course, a video output signal may be used in lieu of or in addition to an audio output signal.

15   The RF section 420 includes an RF transceiver 403 and an antenna 404. Although diversity techniques may be used where applicable, the size and power constraints typical of the headset discourages the use of diversity.

Accessible to the microcontroller are various registers used in performing bandwidth management in a manner described hereafter. In a preferred embodiment,
20 these registers are substantially the same as or identical to the registers of the RPU shown in Figures 3A-3K.

In some instances, the headset may receive communications from other devices that are not received by that headset's RPU. As described hereinafter, it is important that the RPU be made aware of such devices. Accordingly, the RPU periodically
25 requests the headset to transfer to the RPU the contents of the registers of Figure 3J stored within the headset.

In a preferred embodiment of the system of Figure 1, the bidirectional wireless link has a bandwidth approaching or exceeding 5Mbps. The number of personal communications systems that may be accommodated within a single "nanocell" depends
30 on what type or types of personal communications systems are present. A single

multimedia system will consume essentially the entire bandwidth. The same bandwidth will allow numerous "toll quality" (telephone quality) systems to be supported. An intermediate number of hearing health care systems may be supported.

More particularly, in a preferred embodiment, the present bandwidth 5 management techniques are based on a frame rate of 2000 frames per second, each frame containing 2832 clock periods. A single multimedia system requires substantially an entire frame of information for full-quality sound. A hearing health care system requires approximately one fifth of the frame capacity. A telecommunications system requires approximately one tenth of the frame capacity. 10 Using a telecommunications system as a common denominator, the frame may then be divided into 10 timeslots. Each telecommunications system requires a single timeslot, allowing for 10 simultaneous telecommunications users ("ten-person hug") within the same RF space. Each hearing health care user requires two timeslots, allowing for five simultaneous hearing health care users within the same RF space. Each multimedia 15 user requires 10 timeslots for stereo, CD-quality sound, allowing for only one multimedia user within the same RF space.

In one aspect of the present invention, protocols are used to achieve an appropriate timeslot allocation for all of the users in an RF space. In another aspect of the invention, when timeslot allocation alone is insufficient to full accommodate all 20 users, bandwidth allocation is further used to ensure, insofar as possible an acceptable compromise for all users.

More particularly, in a preferred embodiment, various grades of service are defined for the various types of systems. No grade of service is lower than toll quality. Three higher grades of service are provided for, including hearing health care, 25 medium-fidelity multi-media and high-fidelity multi-media. Additional grades of service may also be provided. The data packet formats for the respective data transfer modes may be as follows:

TOLL QUALITY
(Data Transfer Mode 0)

DATA RATE:

EAR TO RPU 8 BIT SAMPLES 8,000 SAMPLES/SECOND
5   RPU TO EAR 8 BIT SAMPLES 8,000 SAMPLES/SECOND

BASIC STRUCTURE:

GUARD BAND
      6 BITS
RPU TO EAR SYNC PULSE
10   3 BITS HIGH
          1 BIT LOW
RPU TO EAR HEADER (MANCHESTER ENCODED, TOTAL 24 BITS)
          8 BITS OF DATA
          4 BITS OF ECC
15 RPU TO EAR(A) DATA (MANCHESTER ENCODED, TOTAL 120 BITS)
          40 BITS OF DATA
          20 BITS OF DATA
EAR(A) TO RPU SYNC PULSE
          3 BITS HIGH
20   1 BIT LOW
EAR(A) TO RPU HEADER (MANCHESTER ENCODED, TOTAL 32 BITS)
          8 BITS OF DATA
          8 BITS OF ECC
EAR(A) TO RPU DATA (MANCHESTER ENCODED, TOTAL 160 BITS)
25   40 BITS OF DATA
          40 BITS OF ECC
GUARD BAND
      6 BITS

HEARING HEALTH CARE
(Data Transfer Mode 1)

DATA RATE:

EAR TO RPU 16 BIT SAMPLES 16,000 SAMPLES/SECOND
5   RPU TO EAR 14 BIT SAMPLES 16,000 SAMPLES/SECOND

BASIC STRUCTURE:

GUARD BAND
        6 BITS
RPU TO EAR SYNC PULSE
10   3 BITS HIGH
        1 BIT LOW
RPU TO EAR HEADER (MANCHESTER ENCODED, TOTAL 24 BITS)
        8 BITS OF DATA
        4 BITS OF ECC
15   RPU TO EAR(A) DATA (MANCHESTER ENCODED, TOTAL 432 BITS)
        144 BITS OF DATA
        72 BITS OF ECC
EAR(A) TO RPU SYNC PULSE
        3 BITS HIGH
20   1 BIT LOW
EAR(A) TO RPU HEADER (MANCHESTER ENCODED, TOTAL 32 BITS)
        8 BITS OF DATA
        8 BITS OF ECC
EAR(A) TO RPU DATA (MANCHESTER ENCODED, TOTAL 504 BITS)
25   126 BITS OF DATA
        126 BITS OF ECC
GUARD BAND
        6 BITS

MEDIUM-FIDELITY MULTIMEDIA
(Data Transfer Mode 2)

DATA RATE:

5
    EAR(A) TO RPU 8 BIT SAMPLES 8,000 SAMPLES/SECOND
    RPU TO EAR(A) 16 BIT SAMPLES 32,000 SAMPLES/SECOND
    RPU TO EAR(B) 16 BIT SAMPLES 32,000 SAMPLES/SECOND

BASIC STRUCTURE:

    GUARD BAND
        6 BITS
10 RPU TO EAR SYNC PULSE
        3 BITS HIGH
        1 BIT LOW
    RPU TO EAR HEADER (MANCHESTER ENCODED, TOTAL 24 BITS)
        8 BITS OF DATA
15   4 BITS OF ECC
    RPU TO EAR(A) DATA (MANCHESTER ENCODED, TOTAL 816 BITS)
        272 BITS OF DATA
        136 BITS OF ECC
    RPU TO EAR(B) DATA (MANCHESTER ENCODED, TOTAL 816 BITS)
20   272 BITS OF DATA
        136 BITS OF ECC
    EAR(A) TO RPU SYNC PULSE
        3 BITS HIGH
        1 BIT LOW
25 EAR(A) TO RPU HEADER (MANCHESTER ENCODED, TOTAL 32 BITS)
        8 BITS OF DATA
        8 BITS OF ECC
    EAR(A) TO RPU DATA (MANCHESTER ENCODED, TOTAL 160 BITS)
        40 BITS OF DATA
30   40 BITS OF ECC
    GUARD BAND
        6 BITS

HIGH-FIDELITY MULTIMEDIA
(Data Transfer Mode 3)

DATA RATE:

5
EAR(A) TO RPU 8 BIT SAMPLES 8,000 SAMPLES/SECOND
EAR(B) TO RPU 8 BIT SAMPLES 8,000 SAMPLES/SECOND
RPU TO EAR(A) 16 BIT SAMPLES 48,000 SAMPLES/SECOND
RPU TO EAR(B) 16 BIT SAMPLES 48,000 SAMPLES/SECOND

BASIC STRUCTURE:

GUARD BAND
10   6 BITS
RPU TO EAR SYNC PULSE
      3 BITS HIGH
      1 BIT LOW
RPU TO EAR HEADER (MANCHESTER ENCODED, TOTAL 24 BITS)
15   8 BITS OF DATA
      4 BITS OF ECC
RPU TO EAR(A) DATA (MANCHESTER ENCODED, TOTAL 1200 BITS)
      400 BITS OF DATA
      200 BITS OF ECC
20 RPU TO EAR(B) DATA (MANCHESTER ENCODED, TOTAL 1200 BITS)
      400 BITS OF DATA
      200 BITS OF ECC
EAR(A) TO RPU SYNC PULSE
      3 BITS HIGH
25   1 BIT LOW
EAR(A) TO RPU HEADER (MANCHESTER ENCODED, TOTAL 32 BITS)
      8 BITS OF DATA
      8 BITS OF ECC
EAR(A) TO RPU (MANCHESTER ENCODED, TOTAL 160 BITS)
30   40 BITS OF DATA
      40 BITS OF ECC
EAR(B) TO RPU SYNC PULSE
      3 BITS HIGH
      1 BIT LOW
35 EAR(B) TO RPU HEADER (MANCHESTER ENCODED, TOTAL 32 BITS)
      8 BITS OF DATA
      8 BITS OF ECC
EAR(B) TO RPU DATA (MANCHESTER ENCODED, TOTAL 160 BITS)
      40 BITS OF DATA
40   40 BITS OF ECC

GUARD BAND
6 BITS

Figures 5 through Figure 11 illustrate various communications scenarios to which the bandwidth management techniques of the present invention may be applied.

5 Referring to Figure 5, the communications space of interest contains a single RPU is communicating with a single earpiece. No other devices are present in the RF space. Hence, there is no nanocell interference in the usual sense. The RF environment may nevertheless be rapidly changing. The earpiece may be moving with movement of the user's head. The RPU may also be moving, for example being swung in a purse. The

10 communications path may further be affected by jewelry, the user's arms and hands, etc. Bandwidth management includes providing a way to maintain the quality of communications in the presence of such variations. In an RF system, for example, any of several different measures may be applied, including diversity and/or power control. In a quadrature system, IQ node selection may also be employed. Figure 6 illustrates

15 a similar case as Figure 5, but with two earpieces instead of one.

In Figures 7-11, multiple systems are present in the RF space. For simplicity, only two systems are illustrated. Both headsets are assumed to be within range of transmissions from both RPUs. Similarly, both RPUs are assumed to be within range of backscatter transmissions from both headsets. The RPUs may be able to

20 communicate directly, or may be limited to communicating only indirectly via backscatter from one or both of the earpieces.

In Figure 7, both of the personal communications systems are assumed to be telecommunications systems. Both systems may therefore be accommodated using timeslot allocation techniques, if necessary. In Figure 8, both systems are assumed to

25 be hearing health care systems. Once again, both systems may be accommodated using only timeslot allocation. In Figure 9, both systems are assumed to be multimedia systems. Bandwidth limitations require that both timeslot allocation and bandwidth negotiation be performed in order to accommodate both systems. In the case of two multimedia systems, bandwidth is sufficient to provide medium-grade service to both

30 systems.

In Figure 10, one system is a telecommunications systems and one system is a hearing health care system. Timeslot allocation is sufficient to accommodate both systems.

In Figure 11, one system is a multimedia system and one system is of another type, either telecommunications or hearing health care. Both timeslot allocation and bandwidth negotiation is required in order to accommodate both systems. If no other systems are present, then bandwidth is sufficient to provide high-medium-grade service to the multimedia system and normal service to the hearing health care system.

Having described the general operation and effect of the present bandwidth management techniques, examples of particular techniques that may be employed for timeslot allocation and bandwidth negotiation will now be described.

In a preferred embodiment, the RPU is the master timing point for the nanocell protocol. The key functions of the nanocell protocol may be described as follows: If two or more RPUs come within operation range of each other, then each RPU will maintain its own master clock, and in addition, will maintain one or more skew registers which define the timeslot(s) in use by itself and neighboring RPUs. The headset is slaved to the RPU. Each packet from the RPU causes the headset to evaluate the current timing to determine if a re-sync operation should occur. If a headset is within range of two or more RPUs, then the headset will maintain sync with the RPU that has the matching serial numbers.

A state engine composed of a primary state machine and a secondary state machine is used in the RPU and in the headset for bandwidth management in accordance with a preferred embodiment of the present invention. Each of the primary nanocell protocol states will be described.

Power on Reset: In this state, the system performs all initial clearing, resetting, and other functions required to power up the system. At the conclusion of these operations, the system enters the System Reset State.

System Reset: In this state the system clears key registers and counters which enable the system to begin normal operations. This state may be entered from any state, entry to this   state is controlled by two potential sources: First is the power

on startup of the system, Second the micro-controller is able to force the system to do

a reset in an attempt to recover from what would otherwise be an un-recoverable error.

Sync Acquisition: In this state the RPU will send serial number identification

packets to the earpiece attempting to hear a sync pulse and return packet from the

5   earpiece. In this state the EAR will listen for a sync pulse and serial number packet

from its' own RPU.

Sync Acquired: Once a Sync pulse has been acquired, we enter the state of sync

acquired, and process the remainder of the packet to determine what type of packet it

is. Once the RPU and EAR are in sync, the data exchange state is entered.

10   Data Exchange: The normal operational state for the system is the data

exchange state. While in this state the RPU and EAR are able to exchange information,

and RPU's are able to exchange data between each other. Within the primary Data

Exchange state, the unit may transition between various secondary states. These

secondary states in particular realize various features of the bandwidth management

15 techniques of the present invention. Prior to describing the secondary states in detail,

various aspects of the present bandwidth management techniques will be more generally

described.

Fundamentally, the bandwidth management techniques of the present invention

are based on Time Division Multiple Access (TDMA). TDMA techniques have found

20 widespread use in cellular telephone systems. However, the communications

environment described herein exhibits several important differences from the well-

known cellular environment. In particular, in the present communications

environment, there are no devices of fixed location (like the base stations of a cellular

system.) Rather, all devices are mobile, with the mobile devices communicating in

25 RPU/headset pairs. (In the case of a binaural headset, a single RPU communicates with

two transceivers independently.) All of the RPUs are peers. Furthermore, RPUs may

be of different types (telecom, hearing health care, multimedia, etc.). Accordingly,

well-known TDMA techniques by themselves do not suffice to achieve robust

communications in such an environment.

Hence, beyond conventional TDMA techniques, several classes of dynamic bandwidth management techniques are provided that together allow robust communications in the present communications environment. These include Jumping, Slot Negotiation, and Bandwidth Negotiation.

5   In the present communications environment, when interference is first encountered, intelligent (not free-for-all) jumping is employed in a first attempt to reduce interference. The RPU/headset pairs are programmed to, upon the occurrence of a predetermined interference event, Jump together to a new timeslot. (Time alignment may also be applied during the Jump, as described more particularly below

10   in relation to Slot Negotiation.) The interference event may be defined in various ways in accordance with quantitative and/or qualitative measures of communications quality. Increasing need for error correction, increasing incidence of bad sync, bad header or bad data, etc., indicate deterioration in communications quality. If the interference persists despite ameliorative measures (e.g., diversity control, power control), the RPU

15   and headset jump. The amount of the Jump is based in part on the information stored in the databases of the RPU and headset, and is based in part on pseudo-random information, such as serial numbers, battery level, etc.

When the RPU and headset "land," the RPU begins transmitting serial number information in the prearranged timeslot, and the headset listens for transmissions by its

20   RPU. The RPU and headset may Jump up to some predetermined number of times in an attempt to avoid interference. If the RPU and the headset are able to communicate successfully, then they resume normal operation. If not, then they proceed with Slot Negotiation.

During Slot Negotiation, the RPU and headset temporarily discontinue attempts

25   to communicate with one another and instead "listen" for synchronization signals in an attempt to characterize the present communications environment. The first synchronization signal detected is arbitrarily designated as the beginning of Timeslot 0. All communications devices are required to periodically enter a Serial Number Exchange state in which a communications device broadcasts its serial number for other

30   devices to hear. The RPU and headset listen for some number of frames (e.g., 32),

sufficient to update their databases and ensure that all communications devices will have participated in Serial Number exchange. At the conclusion of this interval, the databases of the RPU and the headset, including the registers 301J containing device counts for each of the devices within range of the RPU and headset, will have been
5 updated.

In general, the RPU then performs timebase alignment with respect to the device having the highest device count (or, if two or more devices "tie" for the highest device count, the device having the highest device count and the lowest timeslot). Of the devices that it can "see," the RPU, in effect, aligns its timebase with that of the device
10 having the most comprehensive "view" of the communications environment. This arrangement recognizes--in analogous terms--that a person standing in an intersection is in a better position to direct traffic than a person working inside a manhole.

Referring to Figure 13, if the communications environment is represented as a graph in which RPUs and headsets are represented as nodes and nodes that are within
15 sufficiently close range of one another to allow for communications are joined by edges, then a nanocell system may be regarded as the transitive closure of a subgraph of such a graph. Within such a nanocell system, various points of synchronization may be defined. Some devices (e.g., Nodes 5, 6, 8 and 10) will be aligned to the device having the highest device count and (relative to any other devices having the same
20 device count) the lowest timeslot of the entire nanocell system. Other devices will be aligned to devices that locally have the highest device count and the lowest timeslot, but do not have the highest device count of the entire nanocell system. In the example of Figure 12, Nodes 1, 4 and 7 are aligned to Node 3, and Node 2 is aligned to Node 6.

Once the RPU has aligned its timebase according to the foregoing arrangement,
25 if there are one or more empty timeslots, the RPU may attempt to claim them by broadcasting serial number information in the timeslots. If the timeslots are clear and the headset receives the serial number information, it broadcasts the same information back to the RPU (in reverse order). Communications between the RPU and the headset may then proceed. If the RPU does not receive the correct serial number information
30 back from the headset, then a collision may have occurred with one or more other

devices. The RPU then backs off for a pseudo-random time and makes a further attempt.

If no timeslots are available, then in one embodiment, the RPU waits until one or more timeslots become available. A command may be sent to the headset to cause

5 it to produce a synthesized voice message to the effect that service is temporarily unavailable. Similarly, during interference conditions, if an RPU/headset pair would normally jump but there is no free slot to jump to, the pair will continue to communicate as best as possible without jumping. If communications are lost, the headset may of its own accord generate a synthesized voice message.

10 As described previously, the present system is designed to accommodate different types of devices having different bandwidth needs. In the case of telecom, hearing health care and multimedia devices, for example, a hearing health care device normally requires twice the bandwidth of a telecom device, and a multimedia device normally requires ten times the bandwidth of a telecom device. For efficient use of

15 bandwidth, it is preferable that the timeslots used by a single device be contiguous. In this manner, data packets may be allowed to span timeslots, increasing the Maximum Transport Unit (MTU) of the system and increasing efficiency.

The number of timeslots required by a device wishing to transmit may not be available, or if they are available, they may not be contiguous. An important feature

20 of the present invention is to allow for reduced-rate operation of a device, possibly together with simultaneous negotiation with other devices in an attempt to consolidate slots for full-rate operation. The following examples will serve to illustrate bandwidth negotiation features of the present bandwidth management techniques.

Assume, for example, that a hearing health care device which requires two

25 timeslots for full-rate operation, is turned on in a communications environment in which only a single timeslot is available. The RPU will use the available timeslot to engage in a bandwidth negotiation with its headset in which the RPU and the headset will agree to reduced-rate operation. Assume now that a further timeslot becomes available but that it is not contiguous with the timeslot already occupied by the hearing

30 health care device. Assume further that a telecom device is operating in an adjacent

timeslot. The telecom device requires only a single timeslot and hence can occupy any one timeslot without penalty. The RPU of the hearing health care will then use the newly-available timeslot to perform a bandwidth negotiation with the telecom device, offering to exchange the slot in which the bandwidth negotiation is taking place for the

5   current timeslot of the telecom device. The telecom device, because it suffers no penalty, is required to agree to the exchange. The hearing health care device then performs a further bandwidth negotiation with its headset to use the consolidated, contiguous timeslots for full-rate operation.

     The bandwidth negotiation feature also allows system performance to degrade

10   gracefully in high-traffic conditions. For example, a device might currently be using four contiguous timeslots when an interference event occurs. The RPU and headset will then Jump, multiple times if necessary, in an attempt to avoid the interference. If Jumping is not successful, then the RPU and headset will enter the Slot Negotiation procedure. As a result of the Slot Negotiation procedure, it may become apparent that

15   only one timeslot is now available. The RPU may then enter into a Bandwidth Negotiation procedure with the headset to fall back to operating within a single timeslot, the timeslot that has been ascertained during Slot Negotiation to be clear.

     If additional timeslots become available, the device will compete for the additional timeslots and, if it obtains them, will resume operation at full rate.

20   With the foregoing background and understanding, various further details of an exemplary embodiment of the present invention will be described.

     The RPU and the headset have two principal operational modes, Transmit Mode and Receive Mode, and two power conservation modes, Wait and Sleep. In Transmit Mode, the RPU or headset is transmitting data. In the Receive Mode, the RPU or

25   headset is receiving data. In Wait Mode, the RPU or headset is in a partial powerdown mode which is still able to receive data. In Sleep Mode, the RPU or headset is asleep and will only awaken if a trigger event occurs. Possible trigger events include expiration of a wakeup timer, occurrence of an incoming call, initiation of an outbound call, or other external event which requires reactivation of the link.

A detailed pseudo-code description of events during the Transmit and Receive Modes and the various primary states, as well as state transition details, is included as Appendix A.

Various packet types are defined for transferring various types of information
5 between the RPU and headset. Referring to Figure 13A, the type of packet is encoded within the packet header. In the illustrated embodiment, one nibble of header information is used to define the packet type. Another nibble of header information is used for packet-dependent information. Referring to Figure 13B, eight types of packets are presently defined: Idle, Control Parameters, Status Request/Reply, Serial Number,
10 Slot Negotiation, Bandwidth Negotiation, Sync Loss, and Data Transfer.

The basic structure of the data packets is as follows:

RPU TO EAR STRUCTURE

	A. Guard Band	=	6 bits Alternating 0, 1 pattern
15	B. Sync Region	=	4 bits 3 bit times high 1 bit time low. Used to identify sync as well as polarity
20	C. Header Region	=	24 bits (12 bits manchester encoded) 8 bits of header data 4 bits of ECC data
	D. Data Region(s)	=	120 bits (60 bits manchester encoded) 40 bits of data 20 bits of ECC data

EAR(A) TO RPU STRUCTURE

25	A. Sync Region	=	4 bits 3 bit times high 1 bit time low. Used to identify sync as well as polarity
30	B. Header Region	=	24 bits (12 bits manchester encoded) 8 bits of header data 4 bits of ECC data

      C. Data Region   =   160 bits (80 bits manchester encoded)
                                       40 bits of data
                                     40 bits of ECC data

5   If a second earpiece, Ear(B), is present, the foregoing structure is repeated, followed by a guardband. Otherwise, the guardband follows the foregoing structure directly.

        Normally, an RPU or headset will spend most of its time in the Data Exchange state described previously. Within the Data Exchange state, the RPU or headset may

10 transition between various secondary states as follows.

        1. <u>Audio Data Transfer</u>:

        While in this state, the RPU and EARPIECE are exchanging audio data and key status information. A Data Transfer Packet is used to transfer data between the RPU and the headset.

15   If all is well, the following events will occur:

        A) As long as there continue to be good sync and data exchanges occurring, every 32 frames, the serial number state is entered to check that we are still talking to the correct earpiece, and to allow the world to see our serial number, vision counter, and status byte.

20   B) If the RPU hears a Broadcast RPU device, the RPU will signal the earpiece to still maintain our current time slot for control and sync, but to listen to a specific alternate timeslot for audio data.

        If while in the alternate time slot mode, if there is a failure, the earpiece will revert back to the primary timeslot for audio data transfer.

25   C) If the system is a telecom device, and not a hearing health care device, if the RPU detects the end of call, the system will enter the Idle state.

        D) If the RPU control input, or the touch panel are altered in a manner which requires a change in control settings within the earpiece, the RPU will change to the control parameters state to alter the required settings in the earpiece.

E) Every 20 min or so, the RPU will enter the Status state and retrieve key status information from the earpiece. The key status information includes:

    1. Earpiece Battery level

    2. Key system status items

    3. Communications statistics

F) If significant errors occur in the packets, the following events can occur:

    If it is a bad or missing sync pulse:

        If sync counter 0 then

            If the Jump counter < 3 then

                add 1 to the jump counter.

                Set control time slot register to new time slot value based on the RPU control rule set.

                Enter the Sync acquisition mode to reacquire sync.

            If the Jump counter = 3 then

                clear the Jump counter

                Enter the Passive Time Slot negotiation state

        If sync > 0 then

            remain in the data transfer state and attempt to recover the header and data.

    If it is bad header data:

        If header counter = 0 then

            If the Jump counter < 3 then

                add 1 to the jump counter.

                Set control time slot register to new time slot value based on the RPU control rule set.

                Enter the Sync acquisition mode to reacquire sync.

            If the Jump counter = 3 then

                clear the Jump counter.

Enter the Passive Time Slot negotiation state.

If header counter > 0 then

remain in the data transfer state and attempt to recover

the data.

5   If it is bad data:

Supply interpolated data to the audio stream.

If data counter = 0 then

If the Jump counter = 3 then

clear the Jump counter.

10   Enter the passive Time Slot negotiation state.

If data counter > 0 then

remain in the data transfer state and attempt to continue

with next frame.

2. Serial Number Exchange:

15   The Serial Number Packet is used to exchange serial numbers between the RPU
and headset. This allows the units to ensure that a timeslot is only in use by an RPU
and associated earpieces.

The actions in this state are as follows:

A) The RPU sends its' serial number and the flag indicating which ear is to
20 respond.

B) The EAR will send the response which is its' serial number and current
vision counter.

C) Enter the state contained in the next state byte of the exchange packet. This
feature allows the system to do the following:

25   1) If the RPU has noted that our current bandwidth is too high for the
available number of timeslots, we will enter the bandwidth negotiation state
directly from the serial number exchange state to negotiate between the RPU
and its EARPIECE a data transfer rate which is able to fit the current timeslot
configuration.

2) If the RPU has noted that more bandwidth is now available, we will enter the bandwidth negotiation state to increase the bandwidth utilization between the RPU and EAR.

3) If all is well, the RPU enters the Status Request and Reply state to get the contents of the registers of Figure 3J from the headset.

3. <u>Control Parameters Exchange</u>:

A control Parameter Packet is used to exchange control information between the RPU and headset.

The actions in this state are as follows:

A) The RPU sends the control data and the flag indicating which ear is to respond.

B) The EAR will send the acknowledgement back to the RPU.

C) Enter the data Transfer State.

4. <u>Status Request and Reply</u>:

A Status Request/Reply Packet is used to request status information from he headset by the RPU.

The actions in this state are as follows:

A) The RPU sends the request and the flag indicating which ear is to respond.

B) The EAR will send the reply back to the RPU.

C) Enter the Data Transfer state.

5. <u>Passive Timeslot Negotiation</u>:

The actions in this state are as follows:

If we entered this state as the startup of the data exchange state perform the following:

A) Listen in each of the time slots for 100 frames.

B) If there were no serial number frames exchanged during the 100 frames set the time slot register to 0 and enter the serial number exchange state.

C) If there were serial numbers exchanged during the 100 frames, check the vision registers to determine who has the primary vision of the world (as far as we are concerned).

D) Sync our system to the holder of the primary vision.

5 E) Enter the serial number exchange state to lock our earpiece to the new sync structure.

If we entered this state from the audio data transfer state performing the following:

A) Listen in each of the time slots for 50 frames.

10 B) If there were no serial number frames exchanged during the 50 frames set the time slot register to 0 and enter the serial number exchange state.

C) If there were serial numbers exchanged during the 50 frames, check the vision registers to determine who has the primary vision of the world (as far as we are concerned).

15 D) Sync our system to the holder of the primary vision.

1) If the primary vision is self, the RPU will enter the active Timeslot negotiation state to share the fact that we believe we are now "BOSS".

E) Enter the serial number exchange state to lock our earpiece to the new sync structure.

20 6. Active Timeslot Negotiation:

A Slot Negotiation Packet is used by multiple RPU's and their earpieces to negotiate new time slot positions.

The actions in the state are:

A) Broadcast our timeslot information and vision register.

25 B) Listen in each of the time slots for 50 frames.

C) If there were no serial number frames exchanged during the 50 frames set the time slot register to 9 and enter the serial number exchange state.

D) If there were serial numbers exchanged during the 50 frames, check the vision registers to determine who has the primary vision of the world (as far as we are concerned).

E) Sync our system to the holder of the primary vision.

5   1) If the primary vision holder is self, the RPU will retain its' current timing data.

F) Enter the serial number exchange state to lock our earpiece to the new sync structure.

7. Bandwidth Negotiation:

10   A Bandwidth Negotiation Packet is used by the RPU and the earpiece to negotiate a new data transfer rate.

The actions in this state are as follows:

A) The RPU will inform the EAR what data transfer mode will be employed.

B) The RPU will inform the EAR what timeslot will be used for control.

15   C) The RPU will inform the EAR what timeslot will be used for Audio data transfer.

D) Enter the Audio Data Transfer state to begin exchange of audio data.

8. Sync Loss Recovery:

A Sync Loss Packet is used by the RPU and earpiece to signal continued loss

20 of sync pulses even though the data position may be correct. (This forces a re-sync of the RPU and earpiece before they drift out of sync).

The actions in this state are the same as in the Audio Data Transfer state except that a "cautionary" header bit is set to alert listening devices that the subject RPU/headset pair may be drifting apart.

25 9. Idle:

An Idle Packet is used as a time filler and sync transport during system idle time.

The actions in this state are as follows:

A) 20 times per second the RPU will send an IDLE frame to the EAR. The EAR will reply with an IDLE frame. This mode allows the RPU and EAR to remain in sync while reducing the power level by at least 85%.

5   B) If a call is started by the user, or a call is received, we enter the audio data transfer state.

The foregoing states need not be exclusive. An important feature of the present invention is the ability to concurrently use one or more timeslots for audio data transfer and a further timeslot for control and/or negotiation. For example, an RPU that would

10   normally require multiple timeslots for audio data may continue audio transmission in a single timeslot at lower quality when necessary, at the same time negotiating with other RPUs for one or more additional timeslots. A further important application of the capability is to accommodate broadcast devices. In a classroom, conference room, auditorium, etc., it may be desirable for a common transmitter to serve as the audio

15   source for all headsets within range. When an RPU comes within range of such a device (as recognized by the device's serial number, for example) the RPU instructs the headset to listen to the broadcast device for audio information in one or more timeslots but to continue to listen to the RPU in another timeslot for control information. Upon occurrence of certain events, such as when the RPU and headset travel out of range of

20   the broadcast device, the RPU may then immediately resume audio data exchange with the headset.

This feature is particularly advantageous in hearing health care applications. Inside a classroom, for example, a student's headset may listen to a broadcast transmitter that transmits an instructor's voice. Outside the classroom the headset may

25   automatically revert to normal operation in which the headset transmits audio information to the RPU for processing and transmission back to the headset.

More generally, the bandwidth management techniques of the present invention may be practiced both where control information is communicated "out-of-band" with respect to real-time data and where control information is communicated in-band. An

30   example of a communications system in which control information is communicated in-

band is Ethernet. An example of a communication system in which control information is communicated out-of-band is ISDN, in which control information is communicated separately on the D-channel. The bandwidth management techniques of the present invention are applicable to both models of communication.

5   By using intelligent power management techniques, battery life for both the RPU and the earpiece may be significantly prolonged. One technique for achieving increased battery life is to minimize the use of error-correction at the RPU and at the earpiece. Specifically, in RPU transmit mode, if the RPU-to-ear ECC history is bad (as determined from the exchange of status information), then the power level is

10   increased one level if possible. (The power level may already be the maximum allowed level, in which case it cannot be increased.) If on the contrary the ECC history is good, then the power level may be decreased on a trial basis to see if less power may be sufficient.

Recall that RF power for the earpiece is supplied by the RPU in accordance with

15   backscatter transmission by the earpiece. If the ear-to-RPU ECC history is bad, the RPU boosts power during the backscatter transmission period. If the ECC history is good, power may be decreased on a trial basis.

It will be appreciated by those of ordinary skill in the art that the present invention may be embodied in other specific forms without departing from the spirit or

20   essential character thereof. The presently disclosed embodiments are therefore considered in all respects to be illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than the foregoing description, and all changes which come within the meaning and range of equivalents thereof are intended to be embraced therein.

What is claimed is:

       1.   A method of sharing a bandwidth resource among multiple autonomous communications systems comprising a Remote Processing Unit and headset pair coupled by a wireless communications link, the method comprising the steps of:

5   transmitting real-time information from one device of a pair to the other device of the pair;

            experiencing difficulty receiving the real-time information at the other device because of interference from another device pair; and

            if the interference continues, performing at least one of:

10   a jump procedure in which the pair of devices jump to a different portion of the shared bandwidth resource determined to be free;

            a first negotiation procedure in which the Remote Processing Unit aligns its timebase to that of a selected other Remote Processing Unit; and

15   a second negotiation procedure in which the Remote Processing Unit and the headset agree to cease exchanging real-time information within one or more particular portions of the shared bandwidth resource.

       2.   The method of Claim 1, wherein the wireless communications link is a

20 slotted wireless communications link.

       3.   The method of Claim 2, wherein said first negotiation procedure is a slot negotiation procedure.

       4.   The method of Claim 2, wherein said second negotiation procedure is a bandwidth negotiation procedure in which the Remote Processing Unit and the

25 headset agree to cease exchanging real-time information within one or more particular timeslots.

5.   The method of Claim 3, wherein at least one device of the Remote
Processing Unit and the headset of each device pair comprises a clock of a
predetermined nominal frequency and a phase position counter, the method comprising
said at least one of the Remote Processing Unit and the headset performing the steps
5   of:

monitoring the bandwidth resource to detect occurrences of a distinctive
synchronization signal; and

when a synchronization signal is detected, storing, in correspondence to
a timeslot in which the synchronization signal was detected, a phase position
10   determined by the phase position counter.

6.   The method of Claim 5, comprising the further steps of said at least one
of the Remote Processing Unit and the headset performing the steps of:

receiving identifying packets from multiple other devices, an identifying
packet containing an identifier of a sending device together with a count of
15   devices received by the sending device; and

when an identifying packet is received, storing the count in
correspondence to timeslot in which the identifying packet was received.

7.   The method of Claim 6, wherein said at least one device is the Remote
Processing Unit, wherein said slot negotiation procedure comprises the Remote
20 Processing Unit selecting another Remote Processing Unit to be aligned to based on a
stored count of devices received by said another Remote Processing Unit.

8.   The method of Claim 7, wherein said slot negotiation procedure further
comprises the Remote Processing Unit setting the phase position counter in accordance
with a phase position of said another Remote Processing Unit stored in correspondence
25 to said stored count.

9.   The method of Claim 3, where said slot negotiation procedure comprises the Remote Processing Unit communicating with and agreeing with another Remote Processing Unit to alter timeslot assignments.

10.   The method of Claim 9 comprising performing a slot negotiation

5 procedure using one timeslot and concurrently exchanging audio information between the Remote Processing Unit and the headset using another timeslot.

11. The method of Claim 3, comprising the steps of:

performing a jump procedure in which the pair of devices jump to a different timeslot determined to be empty; and

10   transmitting information from one device of the pair to the other device of the pair.

12.   The method of Claim 11, comprising the further steps of:

failing to receive the information at the other device because of interference from another device pair; and

15   in response to the interference, performing a slot negotiation procedure in which the Remote Processing Unit aligns its timebase to that of a selected other Remote Processing Unit.

13.   The method of Claim 12, wherein the steps of performing a jump procedure, transmitting information, and failing to receive the information are

20 performed multiple times prior to performing the slot negotiation procedure.

14.   The method of Claim 1, wherein the wireless link is a bidirectional wireless link.

15.   The method of Claim 3, comprising the steps of:

exchanging audio information between devices of a pair using variable-length data packets, wherein a data packet is allowed to span multiple timeslots; and

5   exchanging other information between devices of a pair using fixed-length packets commensurate in length with the duration of a single timeslot.

16.   The method of Claim 15, comprising the steps of:

exchanging audio information between devices of a pair using multiple

10   timeslots;

experiencing interference with the exchange of audio information;

performing a slot negotiation procedure; and

following the slot negotiation procedure, performing a bandwidth negotiation procedure in which the Remote Processing Unit and the headset

15   agree to exchange audio information using a reduced number of timeslots.

17.   The method of Claim 16, comprising the further step of subsequently performing a bandwidth negotiation in which the Remote Processing Unit and the headset agree to exchange audio information using an increased number of timeslots.

18.   A method of communicating between a broadcast device and a personal

20   communications system comprising a Remote Processing Unit and headset pair coupled by a slotted wireless communications link, the method comprising the steps of:

the broadcast device broadcasting identifying information;

the Remote Processing Unit receiving the identifying information and recognizing the broadcast device; and

25   the Remote Processing Unit instructing the headset to receive real-time data from the broadcast device within at least one timeslot and to receive control information from the Remote Processing Unit within a different timeslot.

- 37 -

19. The method of Claim 18, further comprising:

the headset transmitting real-time information to the Remote Processing Unit during an interval in which the headset is receiving real-time data from the broadcast device.

5   20. The method of Claim 19, further comprising:

the Remote Processing Unit detecting an event and, in response to the event, instructing the headset to receive real-time data from the Remote Processing Unit instead of from the broadcast device.

21. The method of Claim 20, wherein the event comprises the Remote 10 Processing Unit travelling outside the range of the broadcast device.

22. The method of Claim 20, wherein the event is an audio event detected by the Remote Processing Unit from the real-time data transmitted by the headset.
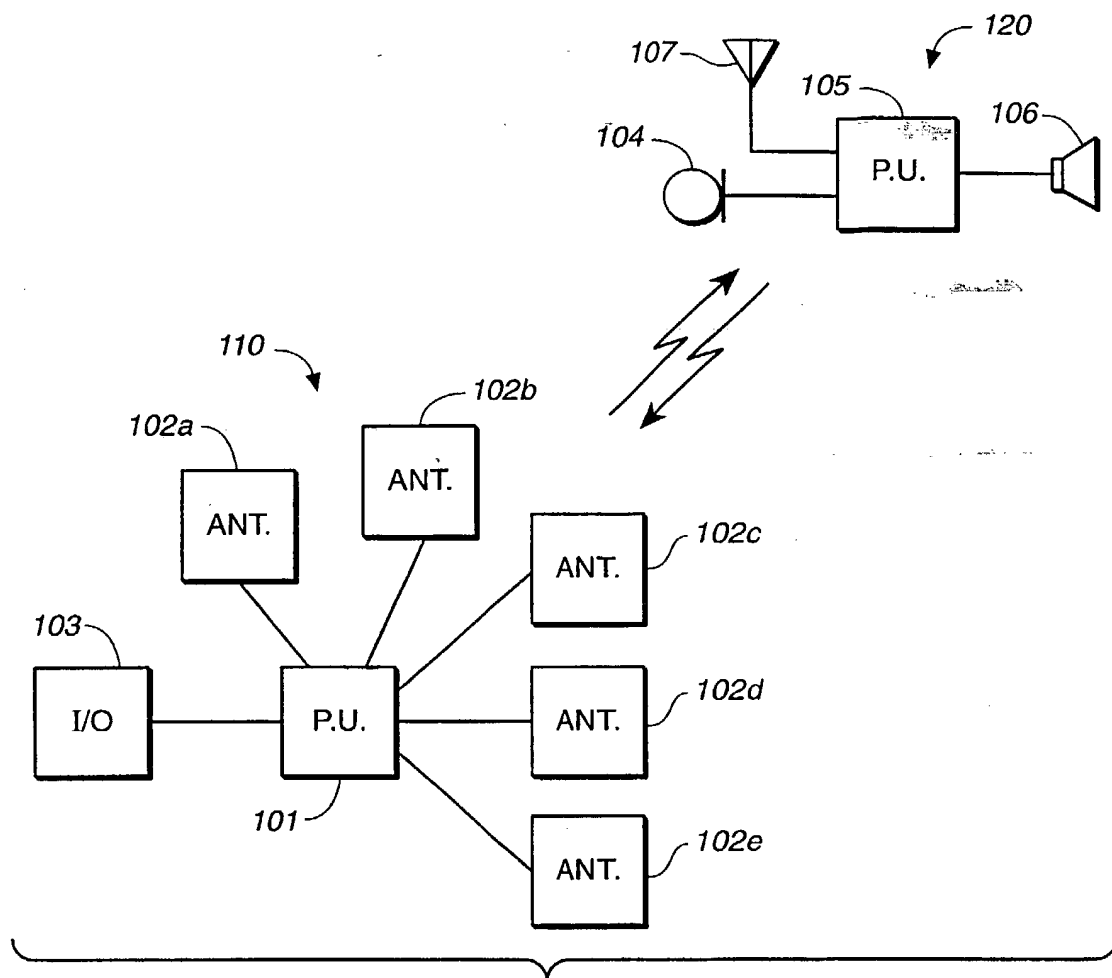
FIG._1

INTERFACE REGISTERS
(DIRECTLY ADDRESSABLE BY MICRO-CONTROLLER)

	BYTE
COMMAND / STATUS 0	
ADDRESS (LOW BYTE)	
ADDRESS (HIGH BYTE)	
DATA TRANSFER	

FIG._3A
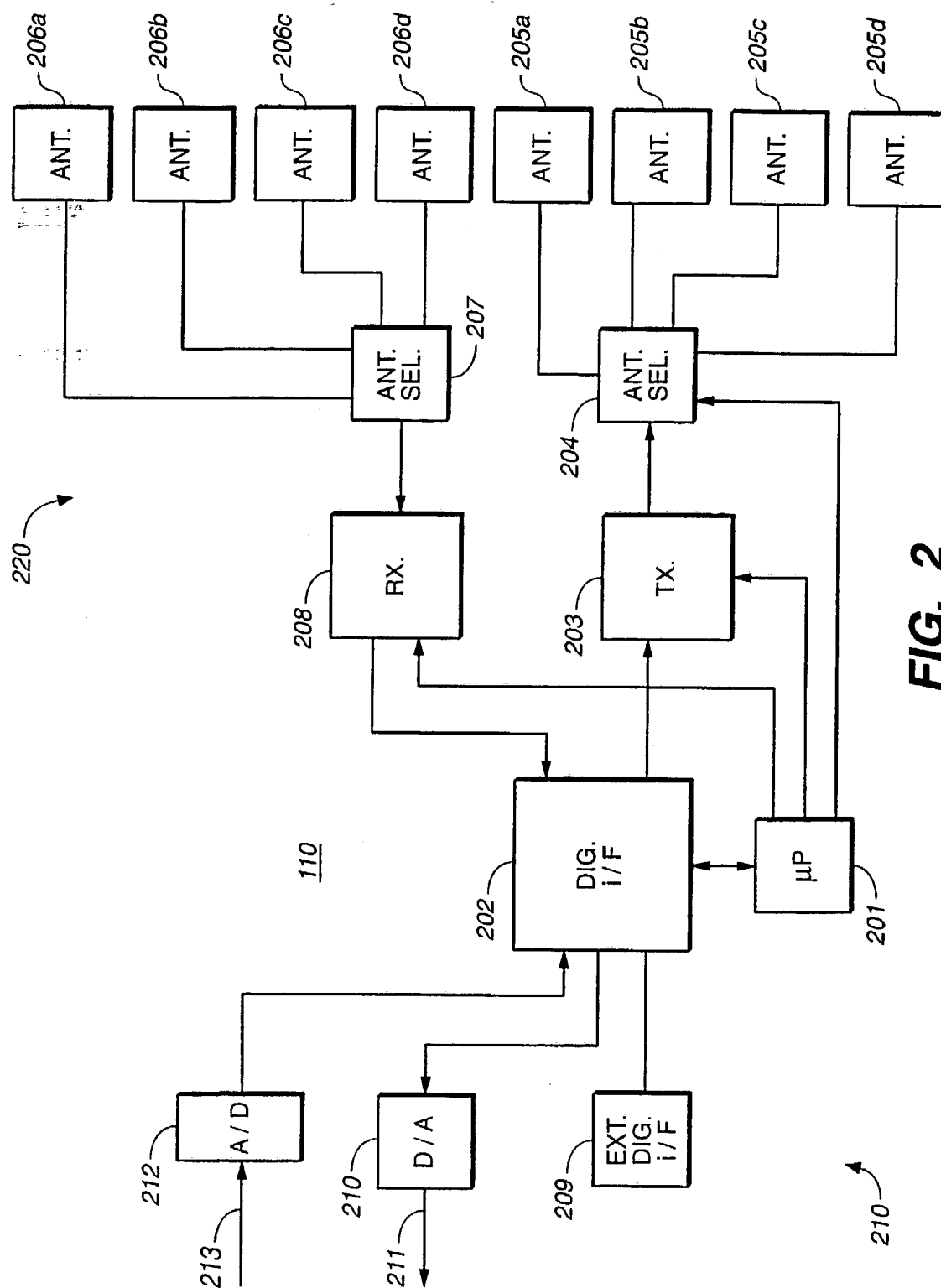
FIG._2

PRIMARY STATUS REGISTERS
(ADDRESS RANGE 0000-000F)

	HIGH BYTE	LOW BYTE
PHASE POSITION		
SYNC COUNT / STATUS		
HEADER COUNT / STATUS		
HEADER ECC COUNT /STATUS		
DATA COUNT / STATUS		
DATA ECC COUNT / STATUS		
INTERNAL COMMAND / STATUS A		
INTERNAL COMMAND / STATUS B		

FIG._3B

PHASE POSITION REGISTERS
(ADDRESS RANGE 0100-011F)
(1 16 BIT REGISTER PER TIME SLOT)

	HIGH BYTE	LOW BYTE
TIME SLOT 0		
TIME SLOT 1		
TIME SLOT 2		
TIME SLOT 3		
TIME SLOT 4		
TIME SLOT 5		
TIME SLOT 6		
TIME SLOT 7		
TIME SLOT 8		
TIME SLOT 9		
TIME SLOT 10		
TIME SLOT 11		
TIME SLOT 12		
TIME SLOT 13		
TIME SLOT 14		
TIME SLOT 15		

FIG._3D

DATA TRANSFER REGISTERS

	LOW BYTE	HIGH BYTE	LOW ECC	HIGH ECC
HEADER				
DATA BYTE 0				
DATA BYTE 1				
DATA BYTE 2				
DATA BYTE 3				
DATA BYTE 4				
DATA BYTE 5				
DATA BYTE 6				
DATA BYTE 7				
DATA BYTE 8				
DATA BYTE 9				
DATA BYTE 10				
DATA BYTE 11				
DATA BYTE 12				
DATA BYTE 13				
DATA BYTE 14				
DATA BYTE 15				
DATA BYTE 16				
DATA BYTE 17				
DATA BYTE 18				
DATA BYTE 19				
DATA BYTE 20				
DATA BYTE 21				
DATA BYTE 22				
DATA BYTE 23				
DATA BYTE 24				
DATA BYTE 25				
DATA BYTE 26				
DATA BYTE 27				
DATA BYTE 28				
DATA BYTE 29				
DATA BYTE 30				
DATA BYTE 31				

FIG._3C

SYNC STATUS REGISTERS
(ADDRESS RANGE 0120-013F)
(2 8 BIT REGISTERS PER TIME SLOT)

	SYNC COUNT	LAST 8 FRAME STATUS
TIME SLOT 0	COUNT OF GOOD SYNC	(1 BIT PER FRAME)
TIME SLOT 1	FRAMES, ADD 1 TO COUNT	(BIT 7 IS OLDEST FRAME)
TIME SLOT 2	FOR EACH GOOD SYNC	
TIME SLOT 3	PULSE, SUBTRACT 1 FROM	
TIME SLOT 4	COUNT FOR EACH BAD OR	
TIME SLOT 5	MISSING SYNC PULSE.	
TIME SLOT 6	A COUNT OF 0 INDICATES	
TIME SLOT 7	TOTAL LOSS OF SYNC.	
TIME SLOT 8		
TIME SLOT 9		
TIME SLOT 10		
TIME SLOT 11		
TIME SLOT 12		
TIME SLOT 13		
TIME SLOT 14		
TIME SLOT 15		

FIG._3E

HEADER STATUS REGISTERS
(ADDRESS RANGE 0140-015F)
(2 8 BIT REGISTERS PER TIME SLOT)

	DATA COUNT	LAST 8 FRAME STATUS
TIME SLOT 0	COUNT OF GOOD SYNC	(1 BIT PER FRAME)
TIME SLOT 1	FRAMES, ADD 1 TO COUNT	(BIT 7 IS OLDEST FRAME)
TIME SLOT 2	FOR EACH GOOD DATA	
TIME SLOT 3	PACKET, SUBTRACT 1 FROM	
TIME SLOT 4	COUNT FOR EACH BAD OR	
TIME SLOT 5	MISSING DATA PACKET.	
TIME SLOT 6	A COUNT OF 0 INDICATES	
TIME SLOT 7	TOTAL LOSS OF DATA.	
TIME SLOT 8		
TIME SLOT 9		
TIME SLOT 10		
TIME SLOT 11		
TIME SLOT 12		
TIME SLOT 13		
TIME SLOT 14		
TIME SLOT 15		

FIG._3F

HEADER ECC STATUS REGISTERS
(ADDRESS RANGE 0160-017F)
(2 8 BIT REGISTERS PER TIME SLOT)

	DATA COUNT	LAST 8 FRAME STATUS
TIME SLOT 0	COUNT OF GOOD ECC	(1 BIT PER FRAME)
TIME SLOT 1	FRAMES, ADD 1 TO COUNT	(BIT 7 IS OLDEST FRAME)
TIME SLOT 2	FOR EACH PERFECT DATA	
TIME SLOT 3	PACKET, SUBTRACT 1 FROM	
TIME SLOT 4	COUNT FOR EACH	
TIME SLOT 5	CORRECTED DATA PACKET.	
TIME SLOT 6	A COUNT OF 0 INDICATES	
TIME SLOT 7	VERY NOISY DATA WITH	
TIME SLOT 8	CONSTANT ECC ACTIVITY.	
TIME SLOT 9		
TIME SLOT 10		
TIME SLOT 11		
TIME SLOT 12		
TIME SLOT 13		
TIME SLOT 14		
TIME SLOT 15		

FIG._3G

DATA STATUS REGISTERS
(ADDRESS RANGE 0180-019F)
(2 8 BIT REGISTERS PER TIME SLOT)

	DATA COUNT	LAST 8 FRAME STATUS
TIME SLOT 0	COUNT OF GOOD SYNC	(1 BIT PER FRAME)
TIME SLOT 1	FRAMES, ADD 1 TO COUNT	(BIT 7 IS OLDEST FRAME)
TIME SLOT 2	FOR EACH GOOD DATA	
TIME SLOT 3	PACKET, SUBTRACT 1 FROM	
TIME SLOT 4	COUNT FOR EACH BAD OR	
TIME SLOT 5	MISSING DATA PACKET.	
TIME SLOT 6	A COUNT OF 0 INDICATES	
TIME SLOT 7	TOTAL LOSS OF DATA.	
TIME SLOT 8		
TIME SLOT 9		
TIME SLOT 10		
TIME SLOT 11		
TIME SLOT 12		
TIME SLOT 13		
TIME SLOT 14		
TIME SLOT 15		

FIG._3H

ECC STATUS REGISTERS
(ADDRESS RANGE 01A0-01BF)
(2 8 BIT REGISTERS PER TIME SLOT)

	DATA COUNT	LAST 8 FRAME STATUS
TIME SLOT 0	COUNT OF GOOD ECC	(1 BIT PER FRAME)
TIME SLOT 1	FRAMES, ADD 1 TO COUNT	(BIT 7 IS OLDEST FRAME)
TIME SLOT 2	FOR EACH PERFECT DATA	
TIME SLOT 3	PACKET, SUBTRACT 1 FROM	
TIME SLOT 4	COUNT FOR EACH	
TIME SLOT 5	CORRECTED DATA PACKET.	
TIME SLOT 6	A COUNT OF 0 INDICATES	
TIME SLOT 7	VERY NOISY DATA WITH	
TIME SLOT 8	CONSTANT ECC ACTIVITY.	
TIME SLOT 9		
TIME SLOT 10		
TIME SLOT 11		
TIME SLOT 12		
TIME SLOT 13		
TIME SLOT 14		
TIME SLOT 15		

FIG._3I

SERIAL NUMBER REGISTER
(VISION COUNT ADDRESS RANGE 0200-020F)
(SERIAL NUMBER REGISTER RANGE 0210-024F)
(SERIAL NUMBERS OF RPU'S WHICH WE SEE)

301J

|	BYTE 0	BYTE 1	BYTE 2	BYTE 3	COUNT
TIME SLOT 0					
TIME SLOT 1					
TIME SLOT 2					
TIME SLOT 3					
TIME SLOT 4					
TIME SLOT 5					
TIME SLOT 6					
TIME SLOT 7					
TIME SLOT 8					
TIME SLOT 9					
TIME SLOT 10					
TIME SLOT 11					
TIME SLOT 12					
TIME SLOT 13					
TIME SLOT 14					
TIME SLOT 15					

FIG._3J

CONTROL AND STATUS REGISTERS

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
STATUS / CTL								
STATUS / CTL B								
UPLINK								
DOWNLINK								
EAR SERIAL 1								
EAR SERIAL 2								
EAR SERIAL 3								
EAR SERIAL 4								
EAR SERIAL 5								
EAR SERIAL 6								
EAR SERIAL 7								
EAR SERIAL 8								
RPU SERIAL 1								
RPU SERIAL 2								
RPU SERIAL 3								
RPU SERIAL 4								
RPU SERIAL 5								
RPU SERIAL 6								
RPU SERIAL 7								
RPU SERIAL 8								
EAR B SERIAL 1								
EAR B SERIAL 2								
EAR B SERIAL 3								
EAR B SERIAL 4								
EAR B SERIAL 5								
EAR B SERIAL 6								
EAR B SERIAL 7								
EAR B SERIAL 8								

FIG._3K

FIG._4

FIG._5   NO INTERFERENCE

NO INTERFERENCE
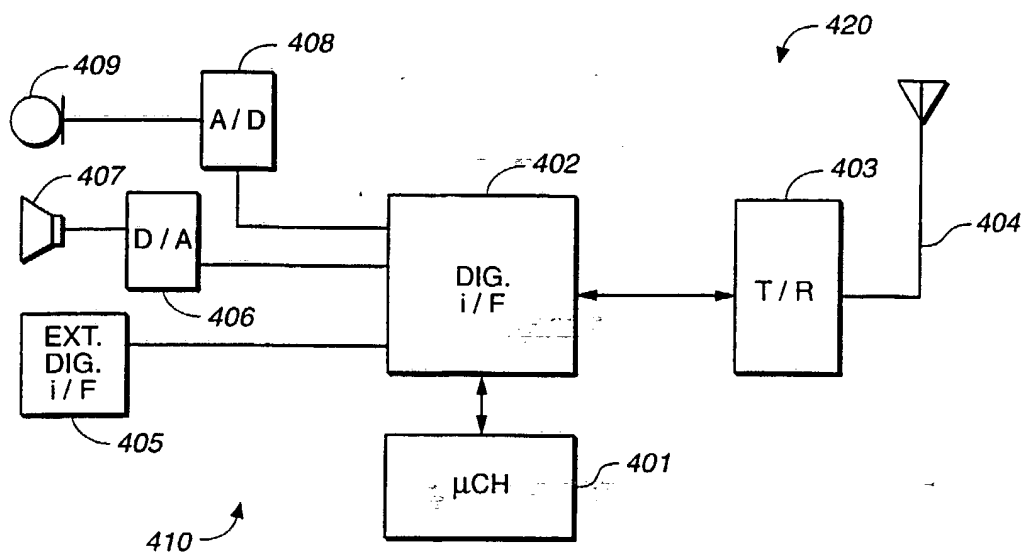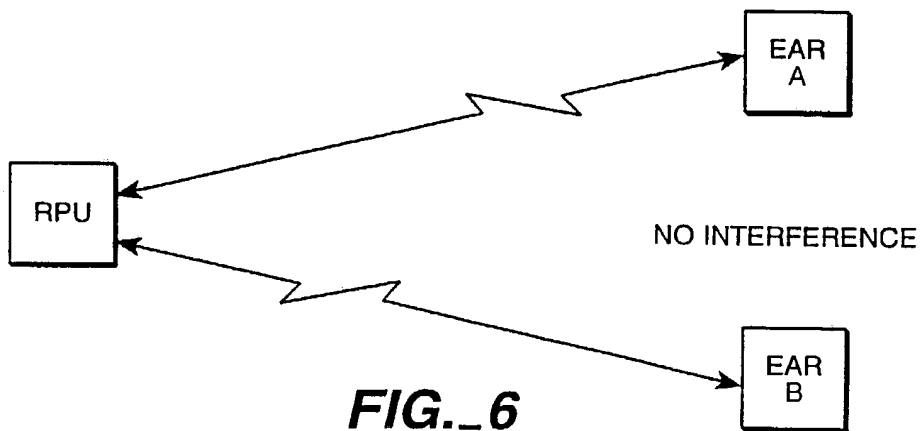
FIG._6
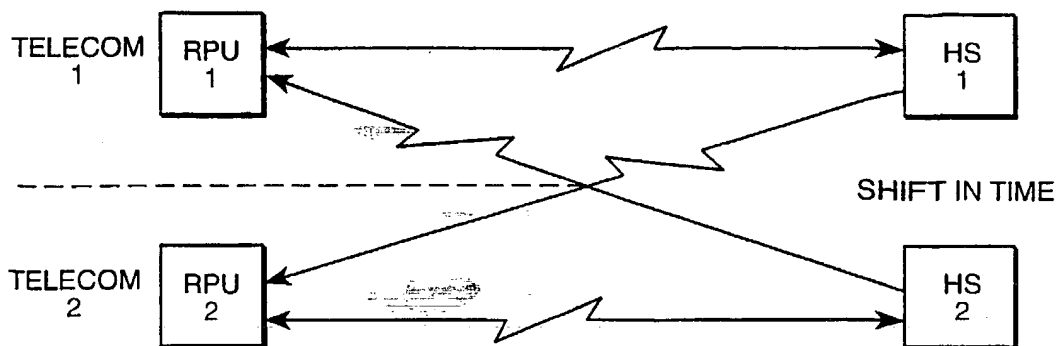
FIG._7
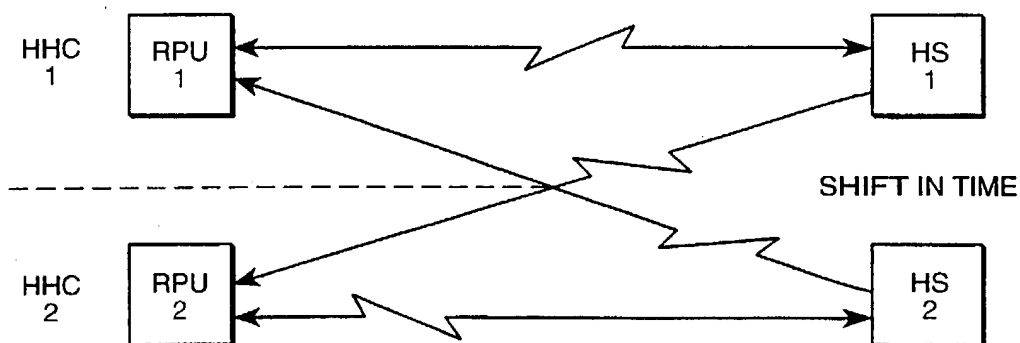
FIG._8
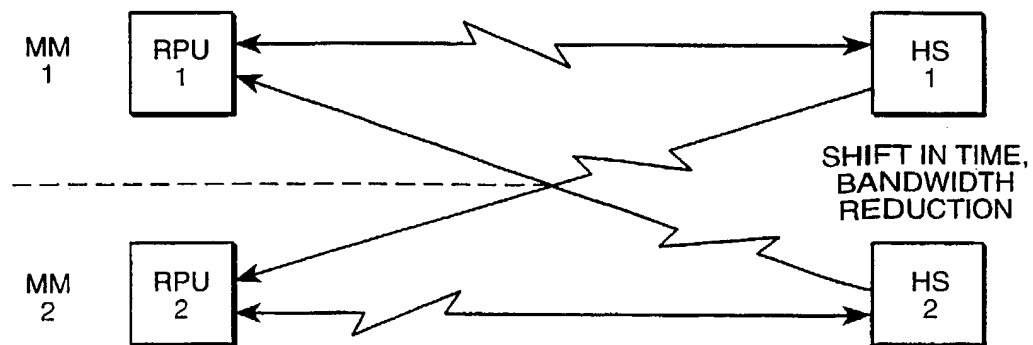
FIG._9
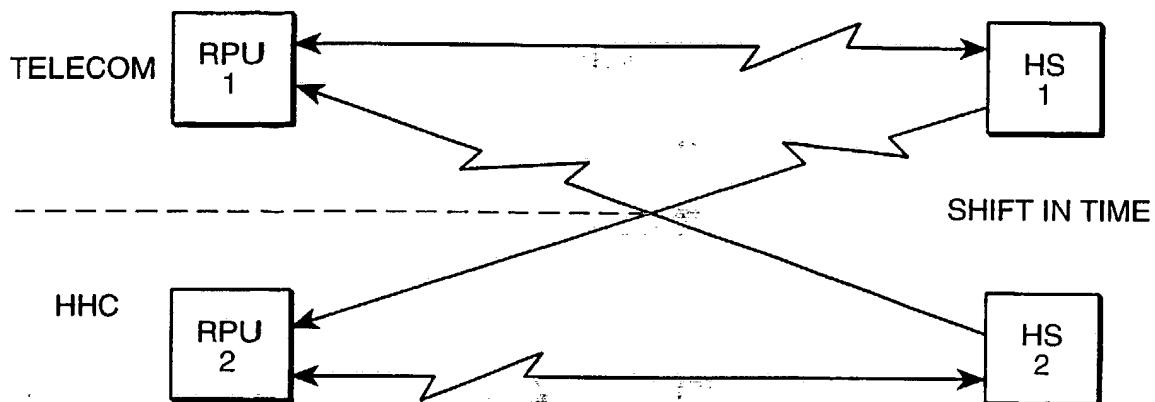
FIG._10
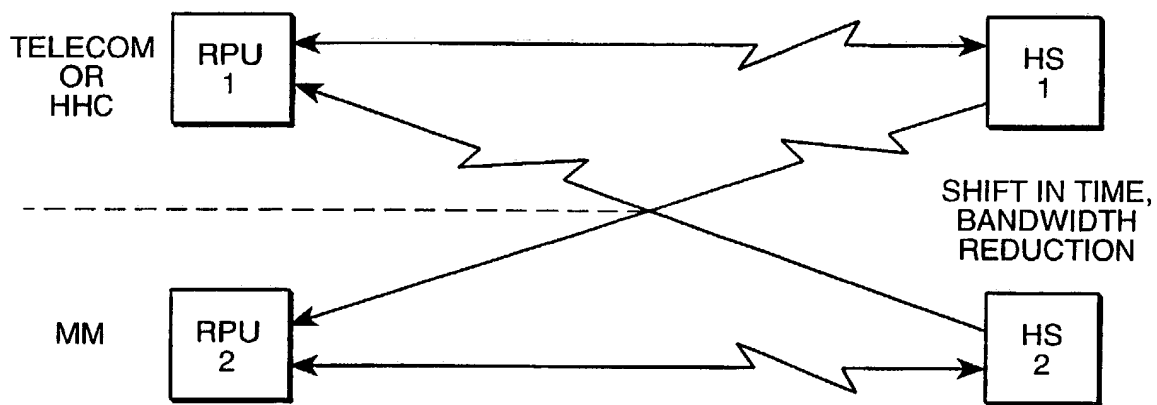
FIG._11
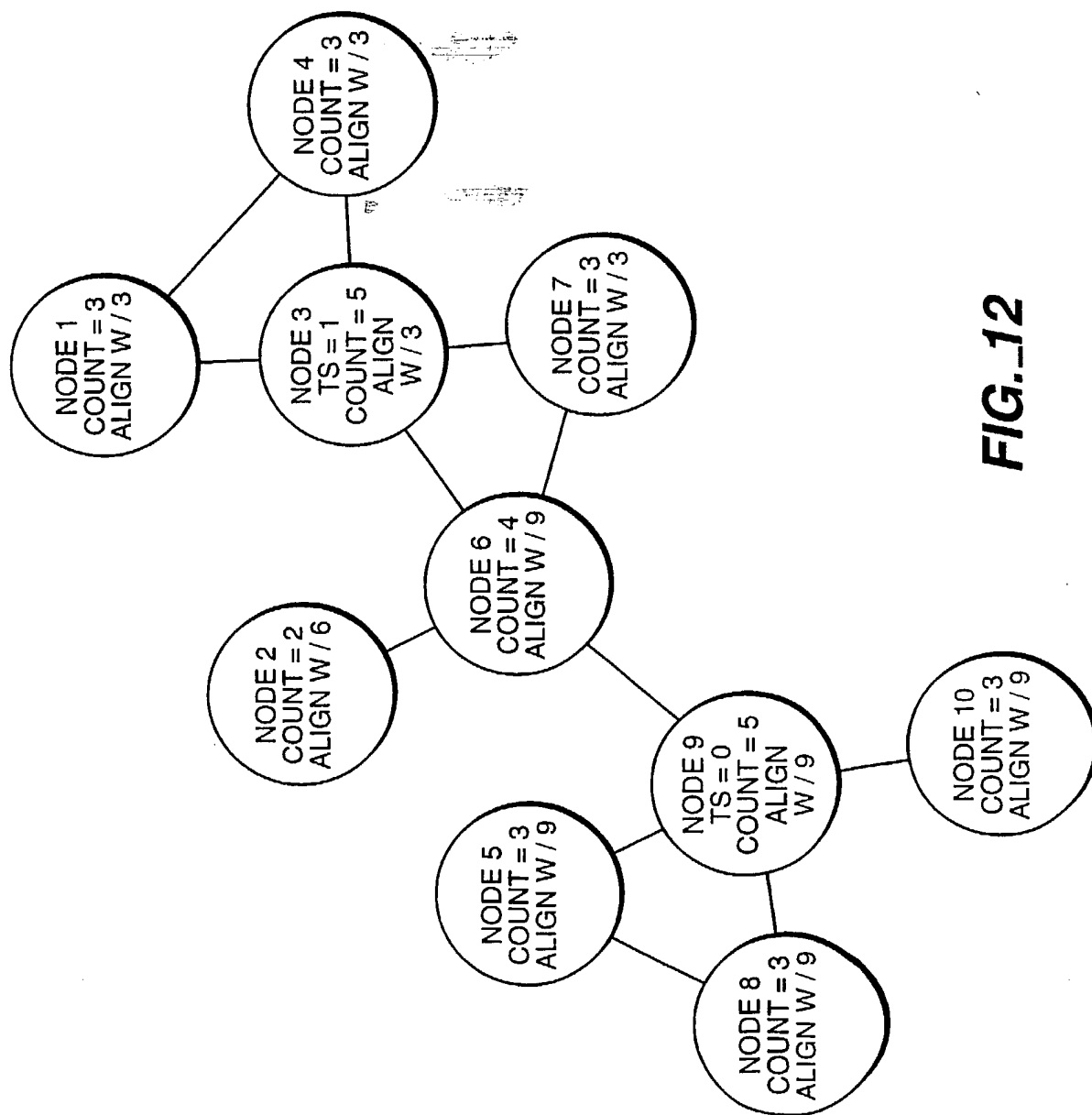
FIG._12

HEADER
(BIT ASSIGNMENTS)

	FUNCTION
BIT 0	PACKET TYPE (LOW ORDER BIT)
BIT 1	PACKET TYPE
BIT 2	PACKET TYPE
BIT 3	PACKET TYPE (HIGH ORDER BIT)
BIT 4	PACKET DEPENDENT INFORMATION (LOW ORDER BIT)
BIT 5	PACKET DEPENDENT INFORMATION
BIT 6	PACKET DEPENDENT INFORMATION
BIT 7	PACKET DEPENDENT INFORMATION (HIGH ORDER BIT)

FIG._13A

PACKET TYPE DEFINITION
(PACKET TYPE VALUE ASSIGNMENTS)

FUNCTION	VALUE
IDLE PACKET	0
CONTROL PARAMETERS PACKET	1
STATUS REQUEST / REPLY PACKET	2
SERIAL NUMBER PACKET	3
SLOT NEGOTIATION PACKET	4
BANDWIDTH NEGOTIATION PACKET	5
SYNC LOSS PACKET	6
DATA TRANSFER PACKET	7
TBD	8
TBD	9
TBD	A
TBD	B
TBD	C
TBD	D
TBD	E
TBD	F

FIG._13B